DESIGN OF A TILTING DAM AND ITS RELATION TO BACKWATER ON THE GUNPOWDER RIVER[1]

By V. Bernard Siems

The water supply of Baltimore is taken from the Gunpowder River, the headwaters of which lie in York County, Pa., near the Maryland line. The river then flows through Baltimore County, Md., in a southeasterly direction, emptying into the Chesapeake Bay about 10 miles northeast of Baltimore. The river, though small, has steep slopes, with a drainage area of 308 square miles above present dam. Its main tributary below the fall line is the Little Gunpowder Falls, which has the same general characteristics as the larger river. There are several small power developments along its course, of which the Warren and Phoenix Mills are the largest.

Previous to 1913 the City of Baltimore received part of its water supply from an impounding reservoir in the Gunpowder Valley, this supply having first been used in 1881. The works for taking this water consist of a stone dam about 25 feet high across the river, about 7 miles northeasterly from the city limits, creating a small reservoir, known as Loch Raven, with an original capacity of 510,000,000 gallons, and an area of water surface of 105 acres. The elevation of the crest of the dam is 171.2 feet. All elevations in this article are based on average mean tide in Baltimore harbor. At this time the city possessed the right to divert 170,000,000 gallons per day from the Gunpowder River. This capacity became largely reduced, by the deposit of silt, until in 1900 the reservoir had a capacity of 178,000,000 gallons. At this time dredging was begun, and continued varying in amount until 1909, with an average cost per year of $25,000. No record of yardage is available for the work was done by department forces.

Starting in 1906 the Water Department made plans for increased storage capacity.

[1] Revision by the author of a paper originally presented by title at the St. Louis convention, May, 1918.

Because of the fact that only $5,000,000 was available for the construction of a new dam and purification plant, the Department decided, in order not to affect the Warren Mills, that the elevation of the crest of dam was to be located at 192.0 (188.0 to 192.0 movable crest), giving a water surface area of 620 acres and a capacity of approximately 2,000,000,000 gallons, which is sufficient storage for an average daily consumption of 90,000,000 gallons, provided both the muddy and clear water were utilized. It was also decided to construct a purification plant to meet conditions for a dam at elevation of 240.0 and a pumping station to lift water to the filters, at an approximate cost of $5,000,000, including the purchase of flooded land (excepting Warren Mills), for a dam with its crest at 240.0.

This dam, built to an elevation of 188.0, is located about 2200 feet upstream from the old dam, and was designed for a width of base at the foundation line (approximately elevation 140.0 to elevation 153.0) adequate for a head at elevation 305.0 feet, this being the maximum height at which an impounding reservoir would be practicable. The area of water surface at this elevation would be approximately 9500 acres, giving a total capacity of reservoir of 142,300,000,000 gallons. From foundation elevation 155.0 to elevation 164.0 base for dam (spillway section) was designed for a head to elevation 240.0. The area of water surface at elevation 240.0 is approximately 2,391 acres, and corresponds to a total capacity of reservoir of 23,660,000,000 gallons. In 1911 the Warren Manufacturing Company filed an injunction prohibiting the building of this dam (crest 192.0). They foresaw a probability of injury to their water-power right at Warren Mills (tail race, elevation 196.0) should the City of Baltimore raise the proposed dam in any manner. The Warren Mills tail race is 7.92 miles above the proposed dam, measured along the axis of the river.

The investigations by the Baltimore City Water Department determined that the backwater curve for a discharge of 24,000 second feet over the crest at elevation 186.0 could not be considered as a governing point in the study of flood curves, because such floods would by themselves interfere with water power at the mill.

The backwater curve for a discharge of 5000 second feet over the crest of the dam (elevation 186.0 or water surface elevation of 192.0) would not show the water surface raised above the normal height at the Merryman Dam (crest elevation 194.3 and 6.80 miles above

proposed dam) of the Warren Mills more than it would be raised by the same quantity of water flowing with the Baltimore City dam not there. Five thousand second feet is over approximately 10 times the average flow and 3 times the maximum flow for the maximum month, and therefore is as large a flood as it is necessary to consider. Injury would not be done by a larger flood other than to affect the quantity of water power available during a few hours.

A flow of 930 second feet would not affect the Warren Mills with a solid dam to a crest elevation at 192.0.

The Baltimore City Water Department, after defeating the injunction, decided to build a masonry dam at elevation 188.0 and then an automatic superdam or tilting dam from 188.0 to 192.0. The masonry dam at elevation 188.0 was completed on November 1, 1913, and in 1917 the tilting dam was installed.

The present spillway has a length of 321 feet at elevation 188.0, and as this crest has keyways for future raising of dam, the center one was utilized for the location of the anchor block, which in turn acts as a pivot for the tilting dam.

To provide a tilting or otherwise movable super-dam in this spillway, in one unit, was impracticable, for structural reasons. More so, however, was this undesirable from the standpoint of waste of water. The tilting dam was arranged so that a portion would tilt when the water reached an elevation of 193.5, giving a depth of 1.5 feet of water on crest of movable dam. If the flood continued to rise, other portions tilt in turn, at different elevations.

The width of spillway was divided into 27 units or separate dams, numbered from 1 to 6. Each numbered section is arranged to tilt at a different height of water over crest. The summary below shows the number of each kind of unit, and the head under which they are designed to tilt:

NUMBER	UNITS	DESIGNED TO TILT AT
1	5	Elevation 194.0 feet
2	6	Elevation 193.5 feet
3	4	Elevation 194.0 feet
4	4	Elevation 194.5 feet
5	4	Elevation 195.0 feet
6	4	Elevation 195.5 feet

It should be noted that all sections are 4 feet (top of spillway to crest of movable dam) except section 1, which is 3 feet 9 inches high. The reason for making section 1 (composed of four 12 foot and one 9 foot sections, a total length of spillway of 57 feet, all at elevation 191.75) lower than the others was because of the desire to confine the normal water flow up to 192.0, also logs, floating ice, etc., to the center of the stream. Section 2 was designed to tilt under the minimum head of 1.5 feet because the intake channel, having an approximate elevation of 170 at the gate house, starts opposite this location (section 2), and therefore by an increased velocity due to the water being confined to this location, the deposit

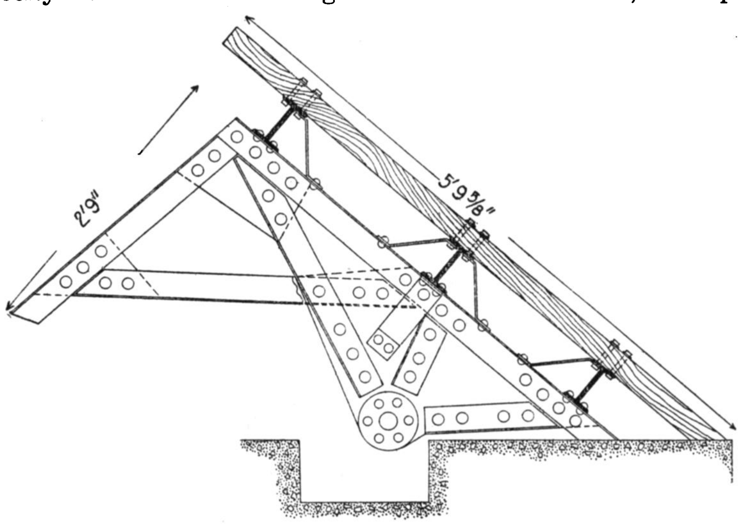

FIG. 1. STEEL FRAME OF TYPE 1

of silt at the end of the tilting dam will be kept away from this channel, and also the channel to the 48 inch sluice gate, whereas if section 1 was made to tilt at the minimum head the deposit of silt would fill the entrance to the channel. Note that section 1 and section 3 were designed to tilt at the same elevation.

The form of dam chosen was that of an obtuse triangle, pivoted at the obtuse angle, and forming a typical hollow or framed dam. As the water rises on a section its center of pressure on the inclined dam surface also rises, and eventually the pressure normal to the back will strike through the hinge. At this time, neglecting the weight of dam, the structure will be in neutral equilibrium. As the

pressure rises still further, the normal strikes above the hinge, and tilting takes place, the crest of the dam falling to take its second, or open, position.

The angle of the back was chosen as 40° with the horizontal, after several trials, as being the most economical of materials and the surest for operation. The horizontal center line of all the hinges is 2 inches above the original spillway, or at elevation 188.17.

The weight of frame 1 is approximately 1212 pounds. Water logging may increase the weight of dam to say 1400 pounds per section. The center of gravity of the dam in section 1 lies $8\frac{1}{2}$ inches upstream from the hinge and 1 foot $7\frac{1}{16}$ inches above the base, in this case, on the horizontal component of the pressure line when the dam is in a normal position. This means that the water must overcome a moment of $\frac{8\frac{1}{2}}{12}$ by 1212 pounds or 862 foot pounds before the dam will tilt, necessitating a further rise of water level sufficient to bring the point of application so far past the hinge that it will cause an unbalanced moment on the hinge.

It is significant that since these dams were installed they have been subjected to high water conditions, and sections 1, 2 and part of section 3 have tilted. Upon subsidence of the water these dams returned to their normal positions. In many cases the elevation varied from 0.3 foot to 0.6 foot lower than that for which they were designed. There can be numerous reasons for this, i.e., as the water subsides and reaches near elevation 188.0, foreign matter lodges at the toe, and when the dam drops back it seats on this obstruction, thereby throwing it forward. This is also the case when any warping of the timber decking at the toe and at the ends of the section takes place. In both cases the tendency is to decrease the head necessary for tilting. On the other hand, friction and corrosion at the pin offer resistance to tilting.

Note that as the dams tilt, the I-beams and timber decking offer some obstruction to the stream. This is especially true as the water subsides. The free waterway from the bottom of the lower I-beam to the concrete top of the dam (elevation 188.0) is 1 foot $2\frac{3}{4}$ inches, giving an opening of 1.2 by 321 feet or 385 square feet, obstructed only by the upright framing of the dam. The tilting dam usually drops back when the water reaches an elevation of 188.75 feet or slightly lower. This proves conclusively that the dams are entirely automatic in their action.

All sections are similar in detail, so that a description of one will cover all cases. Frame 6 (see illustrations) is composed of a deck supported on three I-beams, which are carried by two frames of angles and plates, 8 feet center to center, pivoted separately in cast iron bearings or anchor blocks.

The decking, 6 feet $2\frac{1}{4}$ inches long and 12 feet wide, is composed of first quality, $2\frac{1}{2}$ inch Georgia yellow pine. The I-beams are equally spaced on two frames, and bolted through their lower flanges, further stiffened against twisting by $\frac{3}{8}$ inch bent plates $6\frac{1}{2}$ inches wide, as shown, also bolted to the frame members. The frame is composed of 3 by 3 by $\frac{1}{4}$ inch angles and $\frac{5}{8}$ inch rivets. Pivot pins are 2 inch diameter tool steel turned to $1\frac{15}{16}$ inches. No

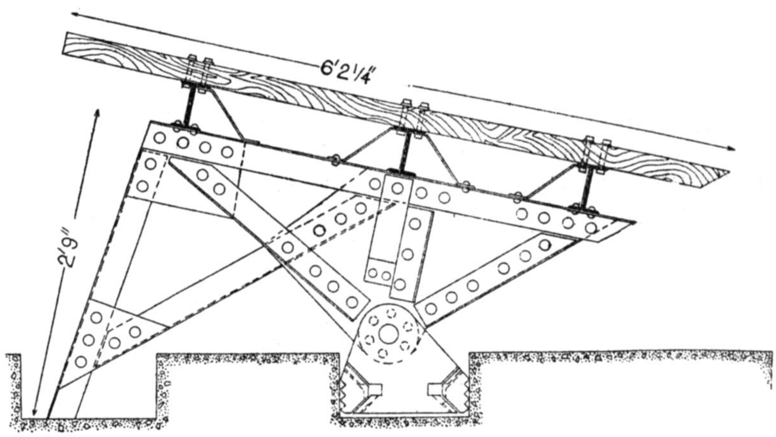

Fig. 2. Steel Frame of Type 6

composition metal was used in the seats, though bearings of bronze would undoubtedly have been used had this work been carried on under usual conditions.

The castings used as bearings or anchor blocks for the dams have several unique features. The center keyway on top of the dam was utilized for anchoring the castings. It was necessary to cut the groove to 14 inches width at the bearings or anchor blocks, as the 12 inch original groove was irregular in alignment and did not give room for lining up the casting. The castings are different for each section of the frame. The distance from the back face of the keyway to the pivot for frame 1 is $4\frac{5}{16}$ inches, and for frame 6 is $8\frac{1}{2}$ inches. The groove for a width of 6 inches having been lined up on

the upstream side, the castings were all set with reference to this edge. The castings are three in number, a center block with a hole for the pin, and two side setting pieces and wedges. The center block was first set to position, then the side pieces slid in and tightened against the sides of groove by wedges. After aligning and wedging in position the spaces under the castings were filled with 1:2 grout, and the spaces between the side pieces and block were filled with lead. This gives an absolutely rigid construction, limited only by the strength of the concrete in the grooves of the present masonry dam.

The total cost of these tilting dams amounted to approximately \$3700. This work was originally offered for contract, two bids being filed, one for \$5275 and the other \$9280. Since the estimate

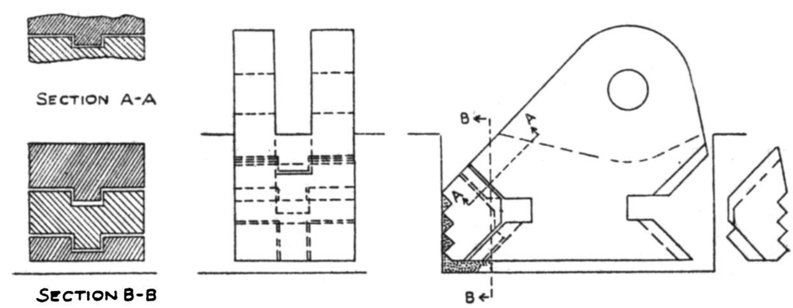

FIG. 3. ANCHOR BLOCK FOR TYPE 1 FRAME

made by the Water Department amounted to \$3200, the bids were rejected and the work done by the Department's forces at the figure above mentioned.

By the construction of this tilting dam and the consequent raising of the water surface from elevation 188.0 to 192.0, a considerable saving in electric power consumption at the low lift pumping station was realized. With an assumed pumpage of 90,000,000 gallons per day the saving was approximately 1500 kilowatt-hours per day, or 547,520 kilowatt hours per year, and at a cost of 0.8 cent per kilowatt-hours, there is a saving of \$4380 per year. These assumptions do not allow for the water surface lower than 188.0 or higher than 192.0, and, therefore, the author would say that the tilting dam paid for itself in not more than a year and a half.

The water impounded behind the new Loch Raven dam flows through a 10-foot circular steel conduit, paralleling the Loch Raven

Drive, until it intersects the 12-foot circular tunnel at the old Loch Raven gate house; thence through a 12-foot circular tunnel to the low lift pumping station at the Montebello filters, a distance of seven miles. It is of interest to note that although the 12-foot circular tunnel was built in 1881, when the amount of water consumed by the city was very small in proportion to the present consumption, it was designed and built of such liberal dimensions that it will be capable of supplying water to a population of at least 1,500,000, and is therefore a valuable asset to the city. The 12-foot circular tunnel is intercepted at the center of the pumping station by a concrete shaft 16 feet in diameter. This shaft extends vertically from the tunnel at elevation 145.94 to the floor of the pumping station at 206.25. The water level in shaft reaches a maximum elevation of 190.0 and varies, of course, according to the elevation of the reservoir at the new Loch Raven dam, the discharge through the tunnel and the loss of head. The shaft acts as a suction chamber for four centrifugal pumps, one 30,000,000-gallon, two 40,000,000-gallon and one 50,000,000-gallon per day capacity, which are arranged around it in radial lines. The water, after passing through these single-stage centrifugal pumps (center line, elevation 198.5) at a maximum rate of 160,000,000 gallons per day, is discharged into a 6.5-foot circular conduit, having a center line elevation at 201.5; thence through an 8-foot circular conduit to the head house, through a mixing basin, coagulating basin, filters and filtered water reservoir to the city distribution system.

When the dam at Loch Raven is raised to a crest elevation of 240.0 the centrifugal pumps will be by-passed and water from the shaft will pass directly through six 42 inch cast iron pipes arranged radially at center line elevation of 201.5 to a $6\frac{1}{2}$-foot circular conduit.

Due acknowledgment is made to John R. Freeman and Frederick P. Stearns, consulting engineers on the water-works improvements, for information received from their report to the Mayor and City Council of Baltimore in 1910; also to S. S. Field, city solicitor, for furnishing information regarding the case of Warren Manufacturing Company vs. The Mayor and City Council of Baltimore.